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Bias-stress stability and radiation response of solution-processed AlO_x dielectrics investigated by on-site measurements

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1. Introduction

To date, solution processes have been developed due to the possibility of low-cost and large-area fabrication without using vacuum deposition techniques. Furthermore, solution-processed high-*k* oxide dielectrics enable the low leakage current, low operation voltage and easy process integration in thin-film transistors (TFTs) [1]. Among various high-k materials, Al_2O_3 is a promising candidate, especially due to its good chemical stability and low oxide/semiconductor interface traps density in a TFT device [2]. The changes in the solution-processed high-*k* materials resulting from bias-stress along with radiation damage have not been fully understood [3] and is a focus of this paper. In general, for a TFT, ionizing radiation could lead to device degradation by generating significant charges in the semiconductors and dielectrics [4]. Moreover, since the interruption of irradiation in conventional off-site radiation response measurements may cause a rapid recovery of the flat band voltage (V_{FB}) shifts, the degradation caused by charge trapping/detrapping of the devices may be underestimated [5]. In this work, solution-processed and atomic layer deposited (ALD) AlO_x thin films were fabricated for comparison. They were integrated into capacitors to investigate the bias-stress stability along with radiation response by on-site measurements [6].

2. Sample Preparation, Results and Discussion

The solution-processed ~150 nm AlO_x films were fabricated by spin coating on n-Si and annealed at 100°C. ALD AlO_x films of ~40 nm were deposited at 100°C using $Al(CH_3)_3$ and H_2O as precursors. Al was deposited as the top electrode to form Metal Oxide Semiconductor (MOS) capacitors. The devices were irradiated by a 662-keV Cs^{137} γ-ray radiation source under different positive/negative gate biases.

The plots of flat-band shift (ΔV_{FB}) under gate bias-stress with/without radiation are shown in Fig. 1. A reversible behavior of ΔV_{FB} is observed under both positive biased irradiation (PBI) and negative biased irradiation (NBI). This indicates that bias-stress dominates the device degradation in short term while radiation effect takes over in long term. Note that the radiation-induced ΔV_{FB} is determined by the generation of oxide traps (ΔN_{ot}) and interface traps (ΔN_{it}) at AlO_x/Si interface. Figs. 2 (a) and (b) present ΔN_{it} of solution-processed AlO_x capacitors under gate bias-stress with/without radiation. ΔN_{it} were estimated by Eq. (1) [7]:

$$\Delta N_{it} = \frac{C_{ox}(\Delta V_{FB} - \Delta V_{mg})}{qA} \qquad (1)$$

where C_{ox} is oxide capacitance, ΔV_{mg} – change in mid gap voltage, q elemental charge and A – area of device. Under PBI, the devices exhibit build-up of Si dangling bonds, which is related to the protons released by radiation. Under NBI, there is a negligible change of ΔN_{it}. Furthermore, ΔN_{it} of ALD AlO_x capacitors is smaller than for solution-processed AlO_x (Figs. 2 (c)-(d)). It has been reported that solution-processed low temperature AlO_x contains a large amount of impurities such as hydroxyl and nitrate groups (also seen in Fourier Transform Infrared spectra of solution-processed samples in the full length paper), which can provide defect states in AlO_x [8].

Figs. 3 (a) and (b) show the energy band diagrams of AlO_x capacitors under PBI and NBI, respectively. When radiation passes through a gate oxide, electron/hole pairs are created [9]. Under PBI, the radiation induced electrons escape from the oxide within several picoseconds due to higher mobility relative to holes. The radiation induced holes in AlO_x could cause negative ΔV_{FB}. Furthermore, some of the radiation induced holes could transport towards the AlO_x/Si interface under PBI, and free hydrogen, in the form of protons [10, 11]. When the protons reach the interface by hopping transport, they react, breaking the Si-H bonds already there, forming H_2 and a trivalent Si defect and cause ΔN_{it} to increase, as seen in Figs. 2 (a) and (b). Full analysis with ΔN_{ot} plots and discussion will be included in the full length paper.

3. Conclusion

The solution-processed and atomic layer deposited AlO_x thin films were fabricated at low temperature. The effects of biased irradiation on AlO_x based MOS capacitors were investigated by an on-site technique. It has been found that radiation can result in reversibility of ΔV_{FB} of solution-processed AlO_x MOS capacitors, which is further analyzed through calculating the radiation induced oxide (ΔN_{ot}) and interface (ΔN_{it}) traps at AlO_x/Si interface. The results suggest that solution-processed AlO_x thin films contain abundant precursor impurities compared to the ALD AlO_x films.

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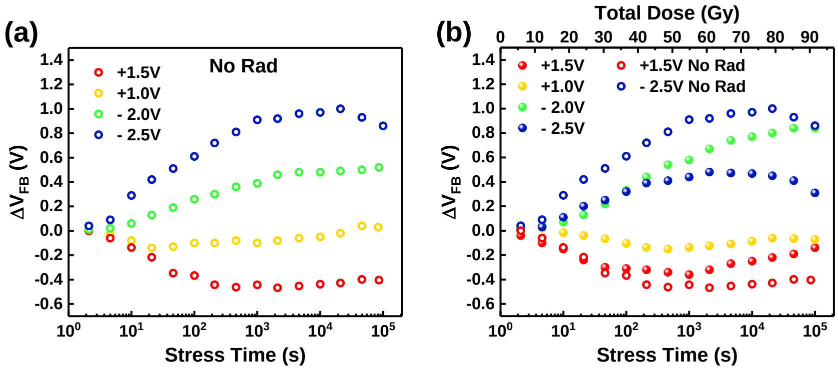

*Figure 1. Flat-band voltage shift (ΔV_{FB}) of solution-processed AlO_x capacitors induced by different positive/negative bias-stress as a function of **(a)** stress time, **(b)** stress time & total dose. ΔV_{FB} was extracted from capacitance voltage (C-V) curves measured from AlO_x capacitors at 1 MHz.*

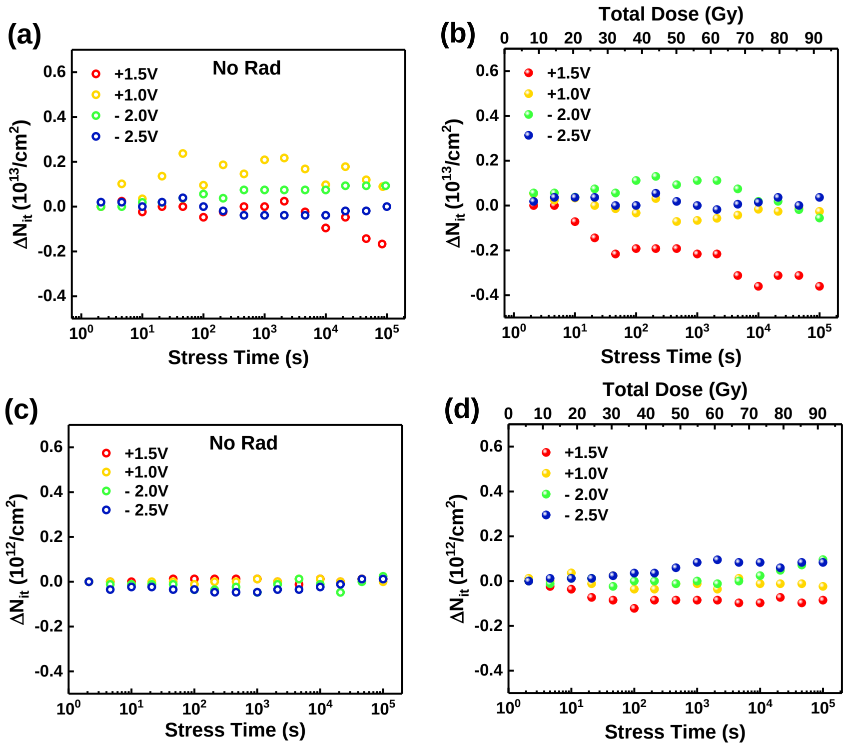

*Figure 2. Variation of interface traps (ΔN_{it}) induced by different positive/negative bias-stress as a function of **(a)** stress time (solution-processed AlO_x), **(b)** stress time & total dose (solution-processed AlO_x), **(c)** stress time (ALD AlO_x) and **(d)** stress time & total dose (ALD AlO_x).*

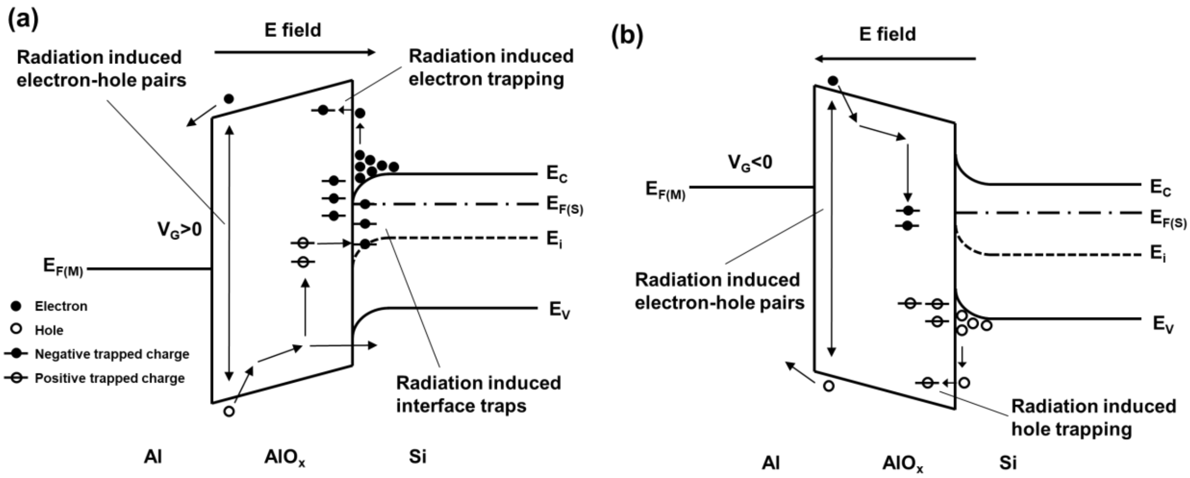

*Figure 3. Energy band diagrams of solution-processed AlO_x capacitors under **(a)** positive biased irradiation (PBI) and **(b)** negative biased irradiation (NBI).*